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FISH-KILL RANGES FOR OIL WELL SEVERANCE EXPLOSIONS.(U)
APR 81 J F GOERTNER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Computations based on the extreme values of compression and extension of the fishes' swim bladder in response to the explosion pressure field were used to estimate lethal ranges from wellhead severance explosions. The computations were done using an equivalent-weight bare charge in free water which was matched to measured data -- shockwave peak pressure, decay constant and impulse -- from a 1/2-scale wellhead-model explosion test. Results are x,y-contour plots of 10%, 50% and 90% kill probability for 1-oz, 1-lb and 30-lb swimbladder fish in water 200, 500 and 1000 feet deep.

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FOREWORD

This report applies the dynamical model for explosion injury to fish developed in NSWC/WOL TR 76-155 to the problem of predicting fish-kill from an oil well severance explosion. This study was funded by the U.S. Geological Survey which has been assigned the task of regulating off-shore drilling operations -- including the removal of abandoned wellheads.

The author thanks his colleagues David O'Keeffe for help with the kill probability computations and Robert Thrun for assistance in using his computer program to make the kill probability contour plots.

J. F. PROCTOR
By direction

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CHAPTER 1

INTRODUCTION

Most countries require that abandoned oil well components be removed from the seabed. Typically, wellheads are severed 15 to 20 feet below the ocean bottom and the freed portions are lifted to the surface for salvage. An explosive charge detonated inside the wellhead casing at the desired severance point is an efficient and popular way of cutting the casing. A major problem with this method is the potential of the severance explosion for killing fish and marine life.

In response to this problem the Naval Surface Weapons Center (NSWC) has recently completed a series of explosion tests to determine the amount of explosive necessary for severance and the resultant pressure field in the water[1]. These tests were done using simulated model wellheads on 1/2 scale. Using these pressure measurements as input for full-scale-explosion computations, this report presents an analysis of the potential of wellhead severance explosions for inflicting unwanted fish-kill. This analysis is restricted to swim bladder fish and is based on the method developed by Goertner[2]. The fish-kill data base used consists of data reported by Goertner[2] and Yelverton et al[3] plus additional unpublished data of NSWC and the Chesapeake Biological Laboratory.

[1]Faux, W. H., "A Cursory Look at the Environmental Effect of the Severing of Oil Wellheads," Transactions of the 1981 Explosives Conference June 9-11, 1981, Houston, TX, Sponsored by the Drilling Technology Committee of the International Association of Drilling Contractors.

[2]Goertner, J. F., "Dynamical Model for Explosion Injury to Fish," NSWC/WOL TR 76-155, 1978.

[3]Yelverton, J. T., et al, "The Relationship Between Fish Size and their Response to Underwater Blast," Lovelace Foundation, DNA Report 3677T, 1975.

The method consists of an approximate calculation for the extreme values of compression and extension of the fishes' gas-filled swim bladder in response to the explosion pressure wave. The calculations are made for the damped radial oscillations of a spherical air bubble in water. The kill probability is then calculated as an experimentally determined function of the ratio of maximum to minimum radius during the oscillatory response.

CHAPTER 2

CALCULATION INPUTS

PRESSURE-TIME INPUT. Three 1/2-scale severance explosions were fired at 7.5-ft depth in a mud bottom under 26 feet of water. Cylindrical charges made from three different explosives--Comp C-4, TNT, and nitromethane--were used to cut the simulated wellhead casings, which were made from steel pipe, with inside diameters of 15, 8 and 5 inches. The annuli between the casings were filled with cement. Total weight of each charge--including pentolite boosters used for the TNT and nitromethane--was approximately 7 pounds. All three charges severed the casings satisfactorily. The Comp C-4 explosion gave significantly higher shock wave peak pressure, impulse and energy flux density in the overlying water. Since we desired a realistic "worst case" for this analysis we selected the underwater shock wave measurements from the Comp C-4 test as input data for this study.

For the purpose of this study it would be irrelevant to characterize the underwater pressure signatures from these severance explosions in all their intricate details. The principal result of the confinement, added mass and attenuation caused by the casing and surrounding bottom material is a considerably lower peak pressure and an increase in the duration of the principal pulse from these explosions. Heathcote[1] reports measured values for the underwater peak pressure, impulse and energy flux density at 22 pressure gage locations on the three underbottom explosion tests. The shockwave impulse, $I = \int p(t)\, dt$, and the

[1]See footnote 1 on page 1-1

energy flux density, $E = \frac{1}{\rho_0 c_0} \int [p(t)]^2 \, dt$, were numerically integrated to 1 millisecond duration. These data together with gage locations relative to the severance charge are reproduced in Table 2-1 for the Comp C-4 explosion. The data are plotted as a function of radial distance from the charge in Figures 2-1 through 2-3. These data are the input pressure data for this study.

In Figures 2-1 through 2-3 separate symbols are used to distinguish between gage locations having different values of polar angle, θ, relative to the vertical direction. Note that all three plots show a simple power law dependence of the dependent variable with range, R, indicated by the straight lines. On the impulse and energy flux density plots these lines were drawn through the data points for polar angle, $\theta \leq 30^0$. On these plots inclusion of the additional data having θ-values in the range, $30^0 < \theta \leq 60^0$, does not appear to change the power law dependence on R. However, it does appear to increase the data scatter (random error).

On the peak pressure plot the line shown is an eye fit to the data, suitable for extrapolation to greater range from the charge. On this plot the data points for θ-values in the range, $30^0 < \theta \leq 60^0$, indicate the higher pressures were measured at these gages.

For use in the computations of this study, the solid lines drawn through the PMAX, I and E data shown in Figures 2-1 through 2-3 were expressed as underwater shockwave similitude equations[4]

$$PMAX = 8510 \left(\frac{R}{W^{1/3}} \right)^{-1.18} \qquad (2\text{-}1)$$

$$I = 0.931 \, W^{1/3} \left(\frac{R}{W^{1/3}} \right)^{-1.11} \qquad (2\text{-}2)$$

$$E = 622 \, W^{1/3} \left(\frac{R}{W^{1/3}} \right)^{-2.23} \qquad (2\text{-}3)$$

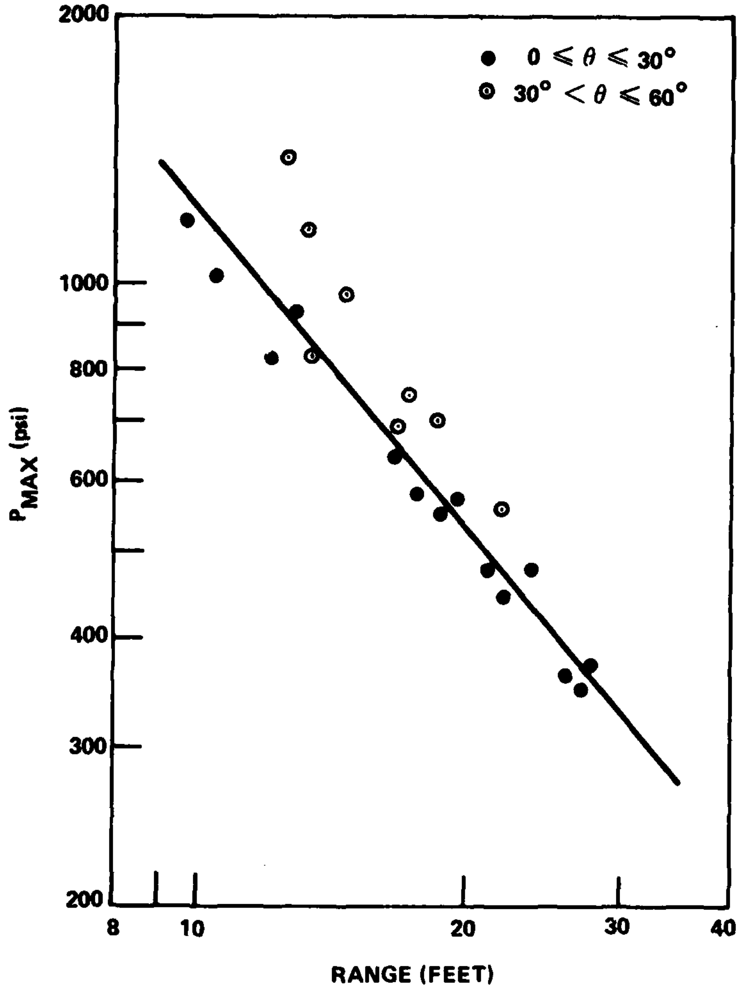
[4]Cole, Robert H., "Underwater Explosions," Princeton University Press, 1948, p. 239.

TABLE 2-1 PRESSURE MEASUREMENTS FROM 1/2-SCALE WELLHEAD SEVERANCE TEST

Charge: 7.0 lb Comp C-4

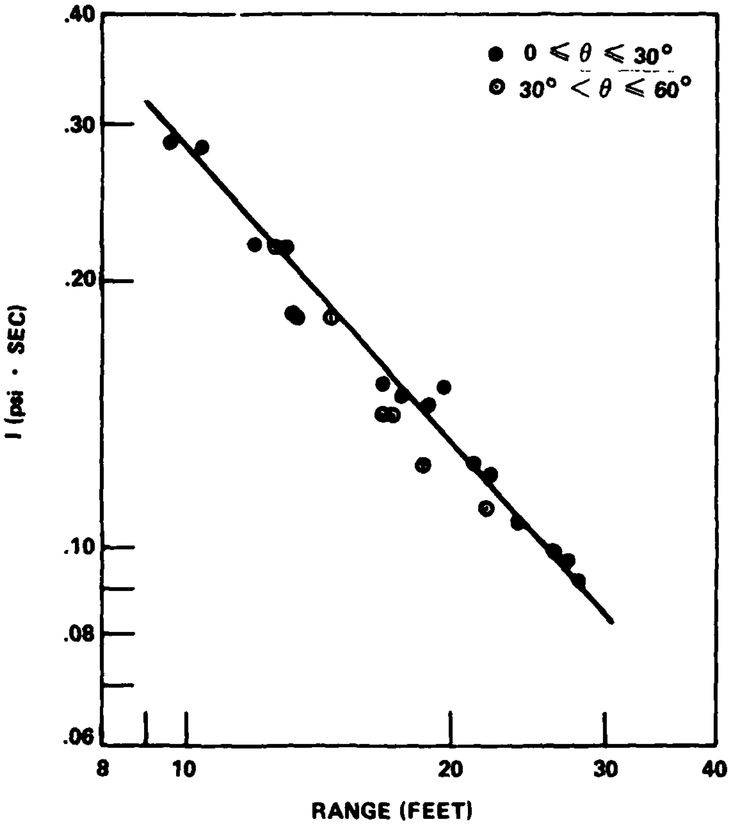
Gage Position	Range (ft)	Polar Angle (deg)	PMAX (psi)	I ($lb\text{-}sec/in^2$)*	E ($in\text{-}lb/in^2$)*
1	9.6	25	1182	0.287	32
2	10.4	23	1017	0.282	28
3	12.0	20	830	0.220	18
4	12.9	18	929	0.218	17.5
5	16.75	14	641	0.153	9.3
6	17.6	14	581	0.149	8.1
7	22.1	11	447	0.121	5.0
8	26.0	9	365	0.099	3.55
9	27.0	9	351	0.096	3.3
10	12.6	46	1386	0.218	19.6
11	13.3	43	1146	0.184	14.8
12	14.6	38	975	0.181	13.4
13	13.4	42	829	0.181	12.7
14	18.8	29	552	0.145	7.4
15	19.6	27	575	0.151	7.2
16	27.8	19	375	0.092	3.1
17	16.75	57	690	0.141	7.3
18	17.25	54	749	0.141	7.5
19	18.6	49	703	0.124	6.6
20	22.0	39	560	0.111	5.1
21	21.2	11	478	0.124	5.5
22	23.8	22	480	0.107	4.3

*Integrated to 1.0 milliseconds



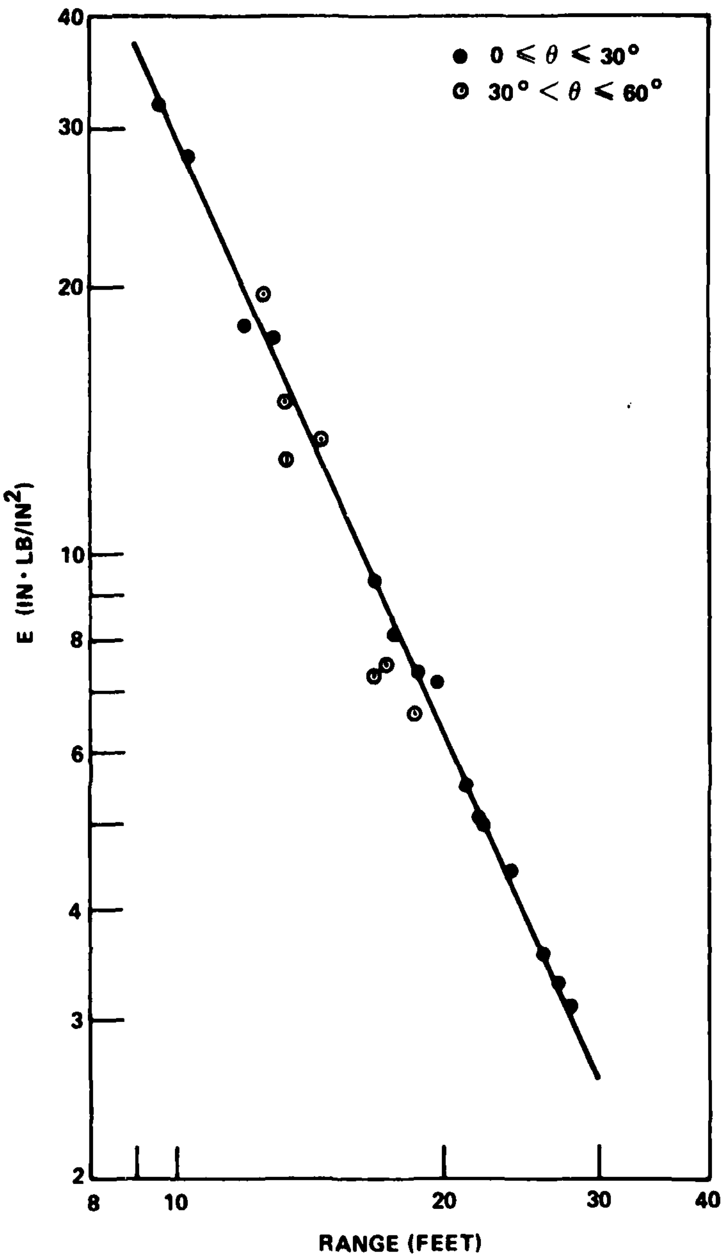
CHARGE: 7.0 LB COMP C-4

FIGURE 2-1 PEAK PRESSURE AS A FUNCTION OF RANGE FROM ½-SCALE WELLHEAD SEVERANCE EXPLOSION



CHARGE: 7.0 LB COMP C-4

FIGURE 2-2 IMPULSE AS A FUNCTION OF RANGE FROM ½-SCALE WELLHEAD SEVERANCE EXPLOSION



CHARGE: 7.0 LB COMP C-4

FIGURE 2-3 ENERGY FLUX DENSITY AS A FUNCTION OF RANGE FROM ½-SCALE WELLHEAD SEVERANCE EXPLOSION

where R is the radial distance from the charge in feet, W is the explosive weight in pounds, PMAX is the peak pressure in psi, I is the impulse in $lb\text{-}sec/in^2$, and E is the energy flux density in $in\text{-}lb/in^2$.

Exponential Pulse Approximation. To facilitate the computations using the dynamical model developed by Goernter[2] we approximated the principal pulse from the wellhead severance explosion by an exponential pulse having peak pressure, PMAX, given by Equation 2-1 and impulse, $I = \int_0^\infty PMAX \cdot EXP(-t/\tau) \cdot dt$, given by Equation 2-2 where τ is the decay constant of the exponential pulse. Since $\int_0^\infty PMAX \cdot EXP(-t/\tau) \cdot dt = PMAX \cdot \tau$, using Equations 2-1 and 2-2 we can express τ as

$$\tau = 109 \times 10^{-6}\ W^{1/3} \left(\frac{R}{W^{1/3}}\right)^{0.07} \qquad (2\text{-}4)$$

where τ is the decay constant in seconds.

EQUIVALENT FREE-WATER EXPLOSION. Due to the short time available for this study we used existing computer programs which were designed for explosions of bare charges in free water for the computations in this report. This necessitated determining the charge weight for a free-water explosion which was in some sense equivalent to a 56-lb Comp C-4 severance explosion buried 15 feet in a mud bottom. Previous discussion with the sponsor, the U.S. Geological Survey, had set the range of full-scale water depths of interest in wellhead severance explosions at 200 to 1000 feet. With these water depths and 15-ft charge burial depth, preliminary computations indicated that the significant fish-kill would occur between ranges of 15 and 1500 feet from the charge. Thus, to make the kill probability predictions for this report, we selected an explosive weight of bare pentolite in free water which roughly optimized the correspondence between pressures signatures - over this range - for the severance explosion (Equations 2-1 through 2-4) and a bare

[2]See footnote 2 on page 1-1.

pentolite charge in free water.* The equivalent weight of explosive selected was 10 pound pentolite, which gives peak pressures, PMAX, over the 15 to 1500 ft range somewhat too high, values for decay constant, τ, somewhat too low, and values for the product, PMAX$\cdot\tau$ -- proportional to the impulse -- which are about as good as we can get by this method (Figures 2-4 through 2-6).

*Price, R. S., Naval Surface Weapons Center, private communication, 1981.

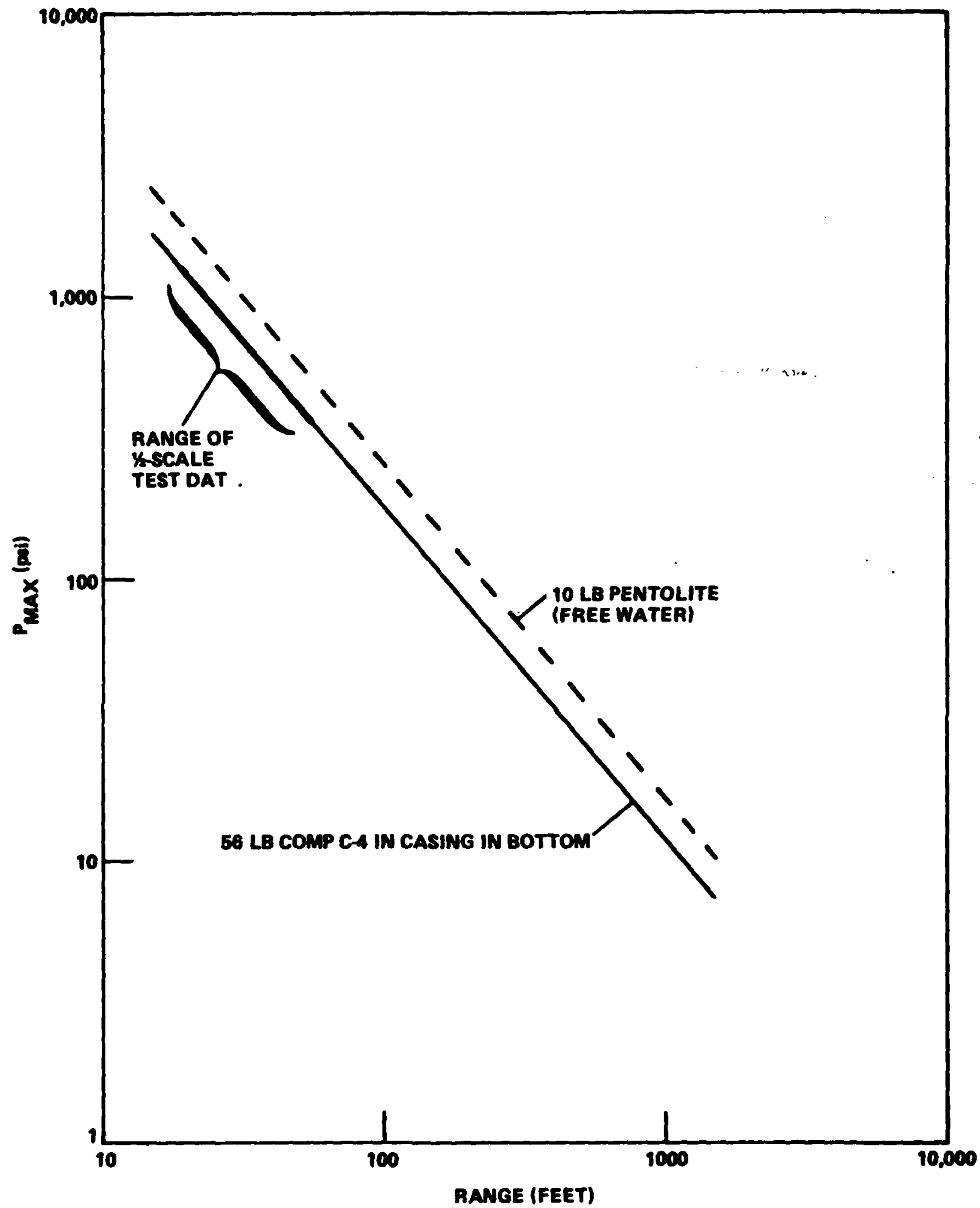


FIGURE ?-4 P_{MAX} – COMPARISON OF EQUATION FOR 56-LB SEVERANCE EXPLOSION WITH 10-LB FREE-WATER EXPLOSION

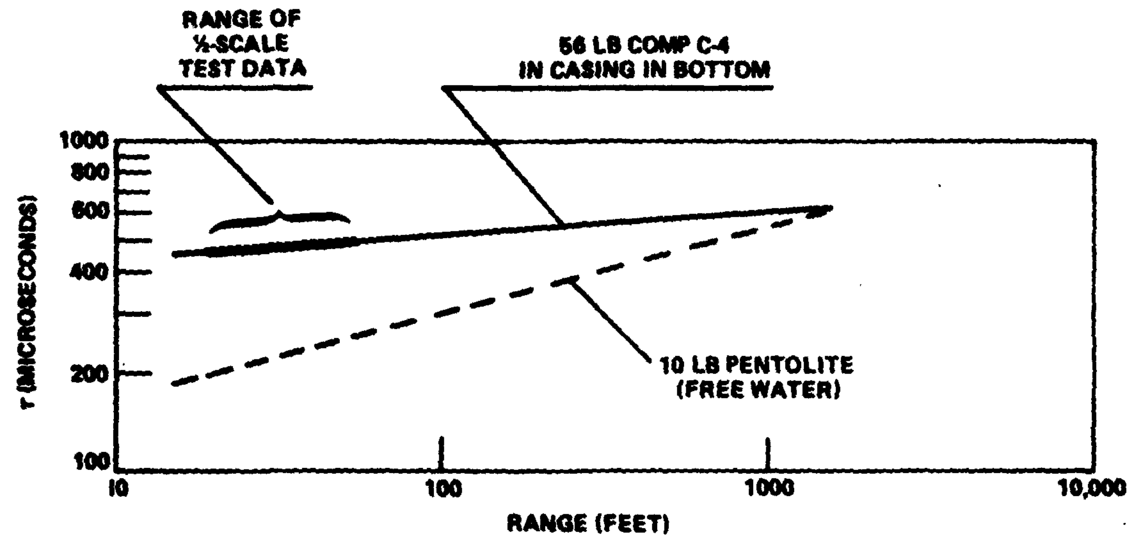


FIGURE 2-5 DECAY CONSTANT – COMPARISON OF EQUATION FOR 56-LB SEVERANCE EXPLOSION WITH 10-LB FREE-WATER EXPLOSION

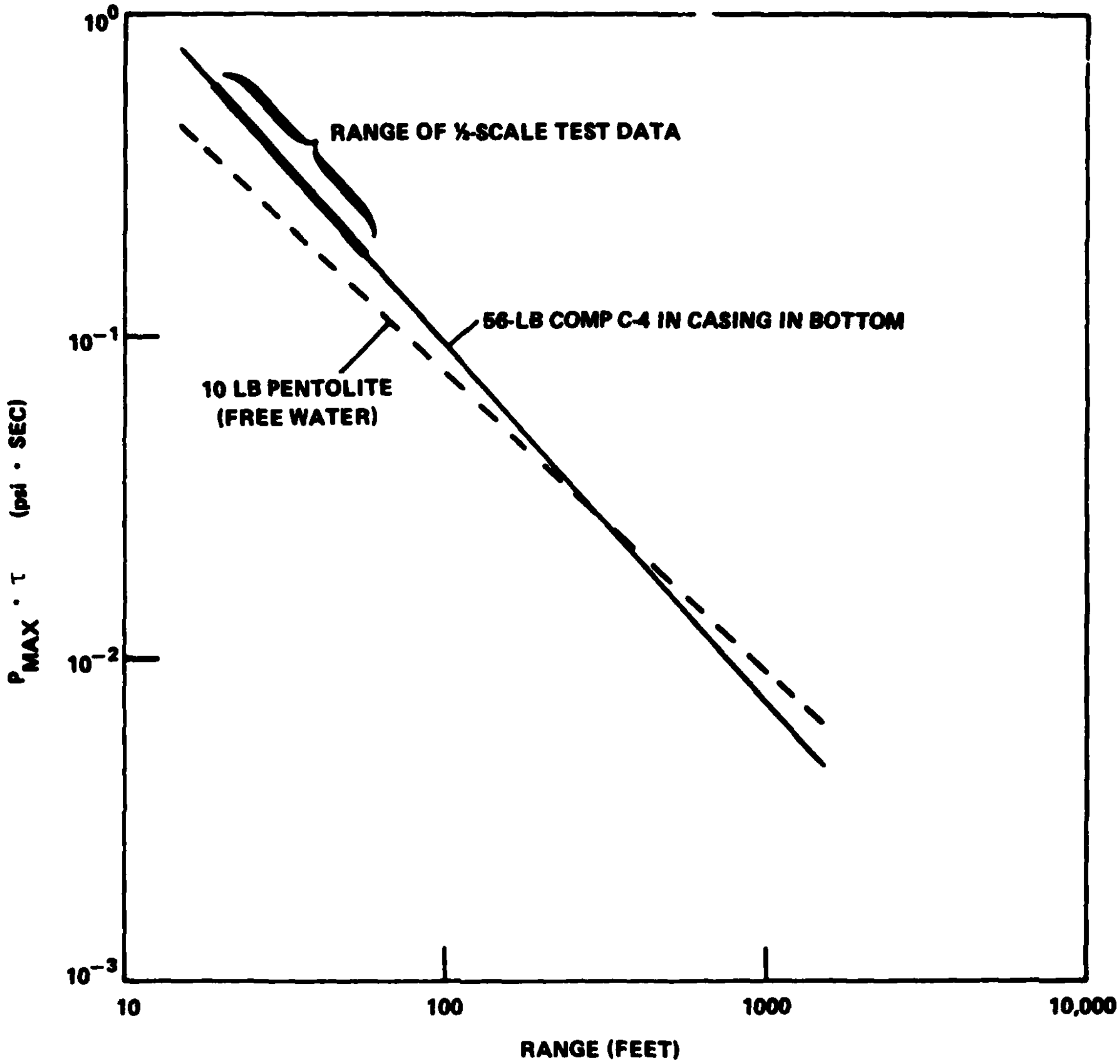


FIGURE 2-6 $P_{MAX} \cdot \tau$ – COMPARISON OF EQUATION FOR 56-LB SEVERANCE EXPLOSION WITH 10-LB FREE-WATER EXPLOSION

CHAPTER 3

KILL PROBABILITY CONTOURS

Figures 3-1 through 3-3 show the results of this study. The pressure field as modified by surface reflection and bulk cavitation was calculated for free-water charge depths of 215, 515 and 1015 feet, respectively, using a 10 pound equivalent weight free-water pentolite explosion. (Figure 3.1.1 of Reference 2 shows the form of a typical pressure signature.) Then for each two-dimensional array of pressure field values, the swim bladder response and corresponding kill probability were calculated for three different sizes of fish. Finally, contours for predicted kill probabilities of 90%, 50% and 10% were interpolated through the two-dimensional arrays of computed kill probabilities (Figures 3-1 through 3-3).

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[2]See footnote 2 on page 1-1

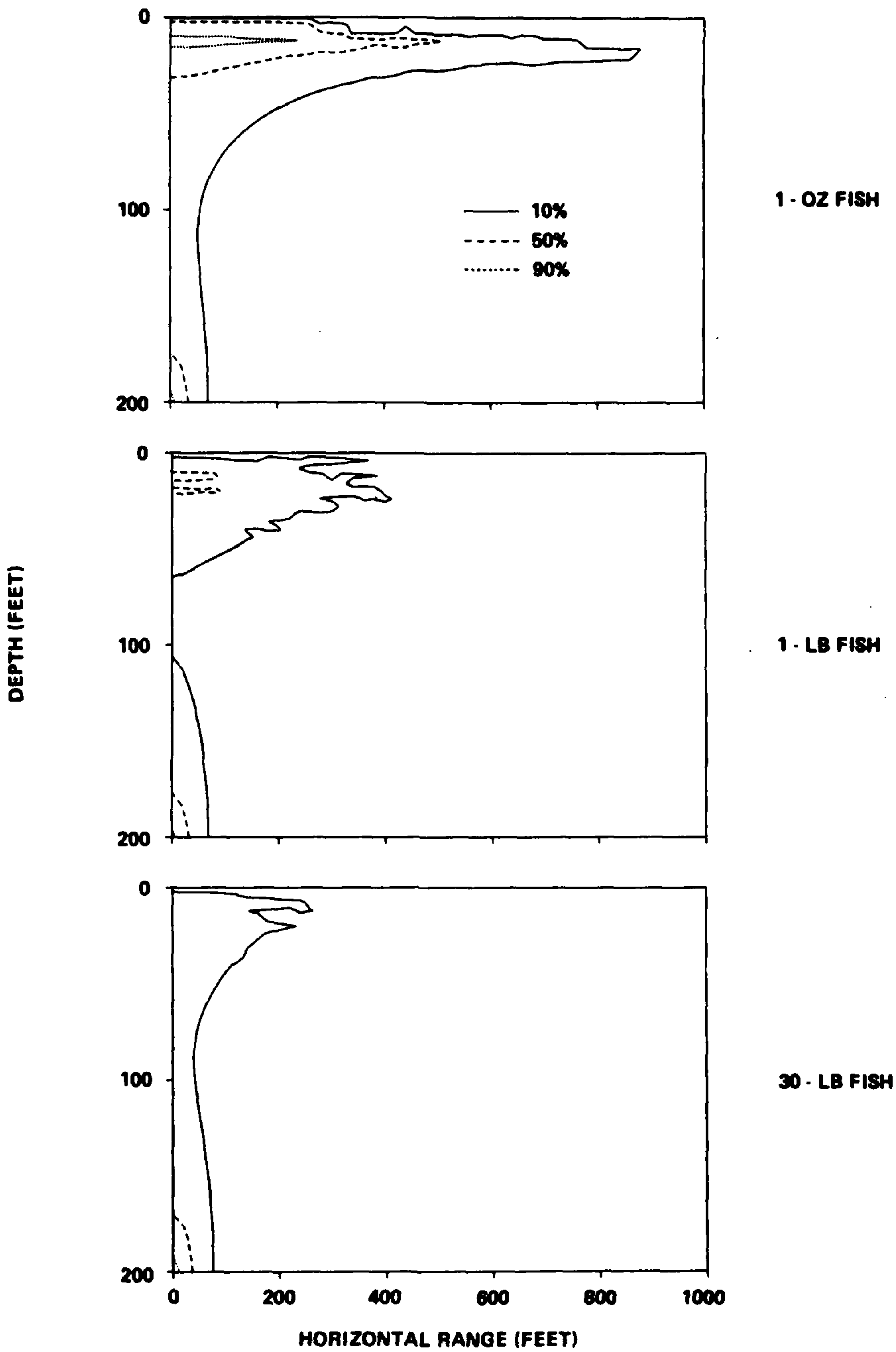

FIGURE 3-1 10%, 50% & 90% KILL PROBABILITY CONTOURS FOR WELLHEAD SEVERANCE EXPLOSION – 200-FT WATER DEPTH

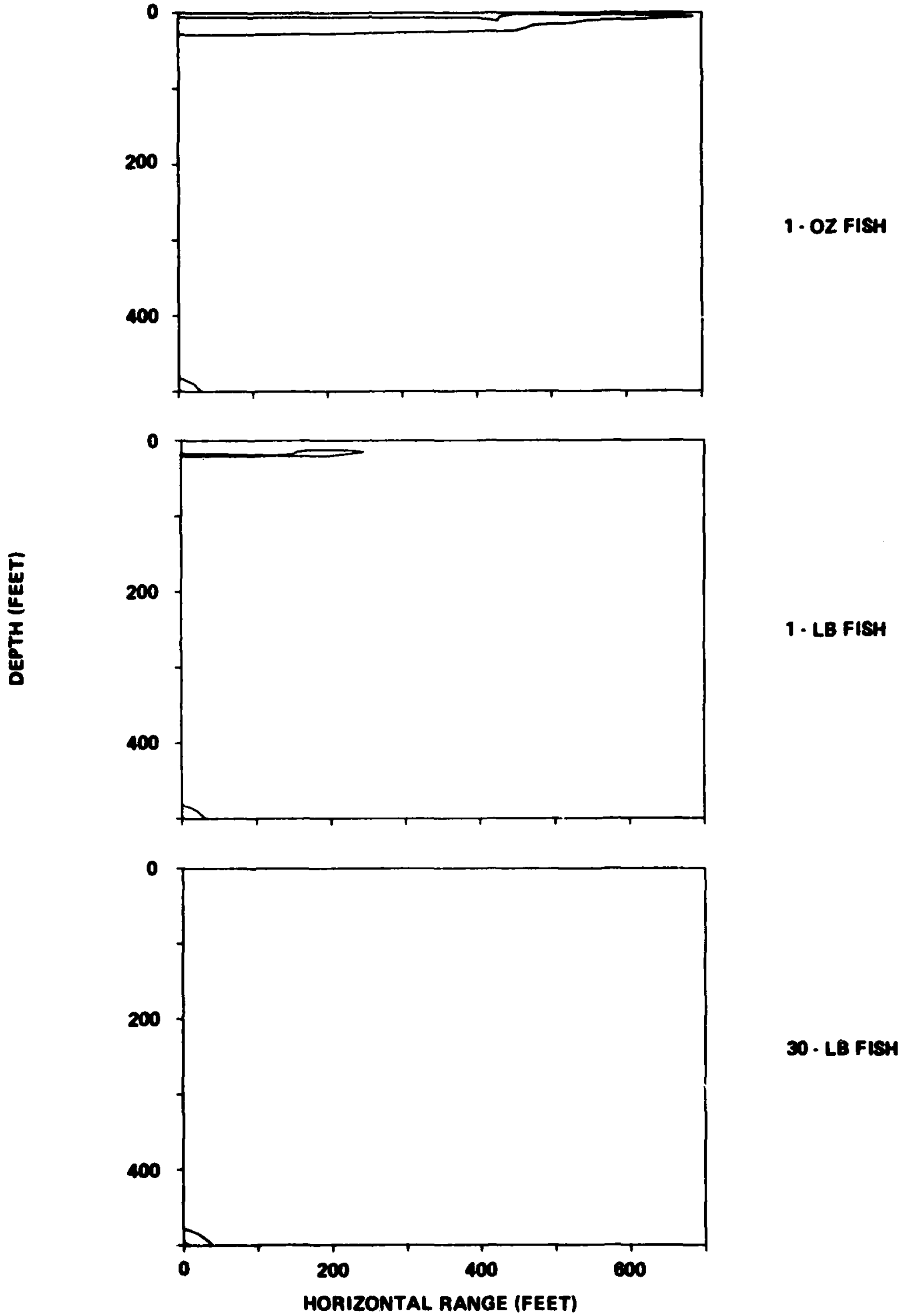

FIGURE 3-2 10% KILL PROBABILITY CONTOURS FOR WELLHEAD SEVERANCE EXPLOSION – 500-FT WATER DEPTH

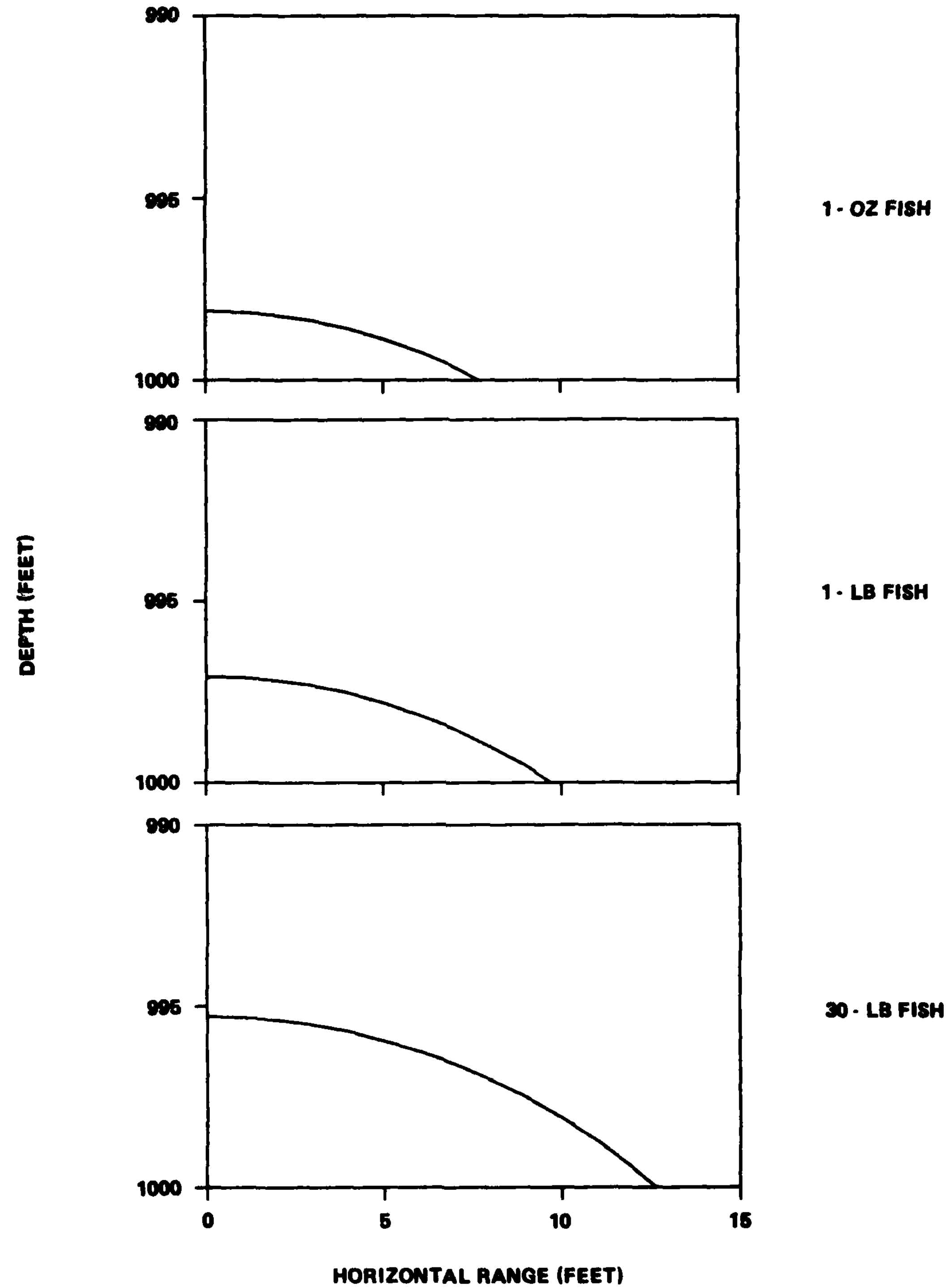

FIGURE 3-3 10% KILL PROBABILITY CONTOURS FOR WELL HEAD SEVERANCE EXPLOSION — 1000-FT WATER DEPTH

CHAPTER 4

CONCLUSIONS

1. For wellhead severance explosions in water depth of 200 feet, significant fish kills can occur near the surface out to a horizontal range of about 900 feet for small fish (1-oz weight). Larger fish near the surface are considerably less vulnerable to explosion injury. One-pound fish near the surface can be killed out to a range of about 300 feet. Near the bottom significant kills of all sizes of fish are limited to a maximum horizontal range of about 70 feet.

2. In water depth of 500 feet, the hazard to all fish is considerably reduced and is probably significant only for small fish. One-ounce fish near the surface can be killed out to a horizontal range of about 700 feet. The only other fish which are vulnerable to injury are those near the bottom in the immediate vicinity of the wellhead -- within a radius of 30 to 40 feet from the charge.

3. For severance explosions in water of 1000-ft depth, no significant kills of swim bladder fish will occur.

CHAPTER 5

DISCUSSION

These results should be considered preliminary and are limited to swim bladder fish. Although these results are based on the close-in pressure field for a 56-lb Comp C-4 severance explosion, they can (and should) be applied to severance explosions using different explosives and charge weights. The uncertainties inherent to the problem of predicting fish-kill are greater than the variations in explosive output among common explosives. And, since the explosive weights for most wellhead severance explosions will -- from practical considerations -- be within a factor of two of the 56-lbs Comp C-4 used for this study, we have not stated the explosive weight on the graphs showing computed fish-kill probability contours (Figures 3-1 through 3-3). In other words, the author believes the results of this report to be valid for wellhead severance explosions in the range, 28 lb $\leq W \leq$ 112 lb, where W is the explosive charge weight.

Possible steps for improving these predictions would include:

- Computation of the pressure field -- as modified by surface reflection and bulk cavitation -- based on the fits to the 1/2-scale severance test data (Equations 2-1 and 2-4).
- Bulk cavitation computations by the method of Gaspin and Price[5] to compare the predicted cavitation regions resulting from the fits to the 1/2-scale severance test data with those obtained by using the free-water pentolite similitude equations.

[5]Gaspin, J. B., and Price, R. S., "The Underpressure Field from Explosions in Water as Modified by Cavitation." NOL Technical Report NOLTR 72-103, 1972.

- Detailed comparison of predictions based on the dynamical model with predictions based on other damage variables, such as energy and impulse.

It should also be stressed that the actual kill at any site depends on the fish population and its distribution in the water column.

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